

A MULTI-PHOTO LEAST SQUARES MATCHING ALGORITHM FOR URBAN AREA DEM REFINEMENT USING BREAKLINES

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ABSTRACT:

High quality digital elevation models (DEMs) are required for a large number of urban applications such as; telecommunication, urban development, and city planning and management. Sudden changes in surface topography weaken existing automatic terrain extraction techniques. The quality of such DEMs needs to be enhanced. This can be accomplished either manually or automatically. Manual enhancement is costly and time consuming. Hence, automatic enhancement is preferred. In this research, a new algorithm is presented to achieve high quality DEMs in urban areas. The proposed algorithm uses both breaklines and image signals in a least squares matching model. Errors in traditional least squares matching models occur due to incorrect modelling at breaklines when a continuous model is used in object surface reconstruction. Breaklines are utilized in this research to impose surface discontinuity in the least squares matching. In addition, the algorithm detect obscured pixels and eliminate them from the least squares matching model. The algorithm is tested using one meter resolution DEMs. Results for five test sites showed that the RMS are reduced from ten to five centimetres. This supports the use of the presented algorithm to refine DEMs in urban areas.

1. INTRODUCTION

Urban area DEMs are required for a variety of applications such as mobile communication, air traffic navigation, urban planning, and environmental studies. Although DEMs can be generated from a wide range of sources such as land surveying, satellite images, laser ranging data, aerial images are the main sources used to generate high quality DEMs in urban and rural areas, (Mikhail et. al 2001). Both manual and automatic techniques are used to generate DEMs. Manually produced DEMs provide high quality elevation data, but they are time consuming and very costly. Automatic terrain extraction (ATE) algorithms are usually employed to generate DEMs automatically. These algorithms are offered by a number of commercial photogrammetric software. The target of ATE algorithms is to establish correspondence between individual points in two or more images automatically. The elevation of ground points are then computed using projective geometry. These algorithms fail to provide high quality DEMs in the present of discontinuous surfaces due to noise, occlusions, and surface discontinuity. As a result, blunders and errors exist in the final products of ATE DEMs and a refinement step is required.

DEMs refinement has been addressed by several researchers. Skarlatos and Georgopoulos (2004) used a pair of stereo images to refine a coarse DEM. Two orthoimages are generated, one for each image. The parallax between the two orthoimages is computed by image correlation methods based on reference and search templates taken from the two orthoimages. The displacement of the best match point is used to compute elevation errors in the DEM. The errors are then used to refine the DEM. A similar algorithm was used iteratively until the parallax becomes below a certain threshold in Amitabh et al. (2005). The root mean square error (RMS) was reduced to 50 centimeters using 1:17000 scale images.

Techniques for generating and refining DEMs using descent and rover imagery for Mars mapping are presented in Xu et al. (2002). During the descending process of a Mars spacecraft, ten

descent images were taken at approximately every half of the altitude. The images are used to generate an initial DEM of the landing site. The DEM is then refined both in accuracy and resolution to form a five-layer hierarchical DEM, with resolutions ranging from one centimeter to one meter. Area-based matching, epipolar constraints, and least-squares matching are used in the refinement process of the DEM. The proposed technique work fine when no surface discontinuity exists, but it is inapplicable in urban areas.

DEM refining using filtering techniques have been widely investigated. A digital filtering technique is used in Passini et al. (2002) to refine automatically acquired DEM using a stationary random function after trend removal. The filtering process was applied to correlation-based DEM. Results using DEMs of 1:6000 to 1:9600 scale and minimum spacing of 10 meters were reported. Different terrain compositions like urban areas, canopy densities, grid sizes, and different photo scales have been investigated. Two-dimensional (2D) Kalman filter is used in Wang (1998) for the refining of DEMs. The RMS for the refined DEMs are reduces by approximately 70%. DEM filtering using 2D Kalman filters and wavelets was investigated in Trinder et al. (2002). The filtered DEM was used for drainage extraction and building recognition. Another filtering method based on the height difference is used in Zhen (2001) to filter outliers from DEMs generated from stereo SPOT images. Filtering techniques usually smooth DEMs and in the vicinity of urban buildings this reduces the DEM quality.

Dragos et al. (2004) used break lines to filter laser-based Digital surface model (DSM). A moving plane interpolation method is used to generate the DSM from a point cloud in a hierarchical approach. First, a rough approximation of the surface is computed. Then, the oriented distances from the surface to the original cloud of points are computed. Each measured elevation is given a weight according to its distance value. The surface is then recomputed using the moving plane under the consideration of weights. The moving plane is trimmed when a break line is crossed. Histogram and iterative smoothing filters are used in Wu (2005) for filtering laser-based DEMs. Laser-

based elevation models provide accurate elevation data, however they are expensive to collect and insufficient to provide surface texture.

Refinement and filtering techniques in the literature are adequate for either small scale DEMs or DEMs with no discontinuities. Hence, there is a need to develop a refinement algorithm that can handle discontinuities in large scale DEMs. This paper implements a least squares adjustment algorithm, Mikhail (1976), to improve the accuracy of a one meter resolution DEM in urban areas. The algorithm takes as input the elevations of the DEM posts, breaklines, and image intensities. The outputs of the algorithm are the adjusted elevations of the DEM. Continuity equations are imposed between neighboring DEM posts. Breaklines are used to keep apart DEM posts that belongs to different surfaces. As a part of the algorithm, image intensities, from non-obscured pixels, are employed in a least squares matching model. The elevations of the DEM posts are changed to minimize the differences between the gray levels of the corresponding pixels in the employed aerial images. The DEM used in this paper is generated using the SocetSet® photogrammetric software. The ATE technique used in the software is presented in Zhang et al. (2006). Using the presented refining algorithm, the RMS of five DEMs were reduced about 50%. The rest of the paper is organized as follows. The algorithm is proposed in the next section. Experiments and results are then presented. In the last part, conclusions are discussed.

2. METHODOLOGY

The least square adjustment algorithm implemented in this research includes two parts. In the first part, four continuity equations are used between each DEM post and its eight neighbors. However if a breakline exists, the continuity equation is eliminated. In the second part, image intensities from five aerial photos taken for the same site are employed in a multi-photo least squares matching model. For each image pair, one observation equation is written between the intensities of corresponding image pixels in both images. This leads to four observation equations. These equations are written as a function of the DEM post elevation. However, if the pixel is obscured, then the observation equation is eliminated. The objective of the multi-photo least squares matching model is to minimize the differences between the gray levels of the corresponding pixels in the employed aerial images via changing the elevation of the DEM post. The next three subsections present the details of the algorithm.

2.1 Observation equations for surface continuity

Adjusted elevations of all DEM posts are assumed unknowns, in the surface continuity observation equations. The measured elevations are used as the observed values for these unknowns. For each DEM post, one observation equation is written between the observed value and the adjusted value (Eq. 1).

$$F_{ij,0} = Z_{ij} - (l_{ij} + v_{ij}) = 0 \quad (1)$$

where $F_{ij,0}$ = real observation equation,
 Z_{ij} = adjusted elevation for post (i,j),
 l_{ij} = observed elevation for post (i,j),
 v_{ij} = residual of the elevation for post (i,j).

Continuity equations are imposed between neighboring posts. For each DEM post four continuity equations are written in the North-East, Northeast-Southwest, Northwest-Southeast, and East-West directions. These are represented by four pseudo observation equations. However in the vicinity of breaklines, surface discontinuity is imposed and these equations are eliminated. Figure 1 shows the distribution of the eight neighboring posts of a center post and the directions of the four continuity equations.

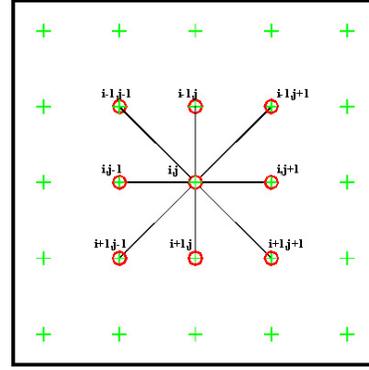


Figure 1. Continuity directions for post (i,j)

All possible continuity equations are generated between all neighboring DEM posts. However, if the line segment connecting two DEM posts intersect with a breakline, the continuity equation between these two posts is eliminated from the adjustment. The pseudo observation equations are shown in Eq. (2).

$$\begin{aligned} F_{ij,1} &= Z_{i-1,j-1} - 2Z_{i,j} + Z_{i+1,j+1} - f_{ij,1} = 0 \\ F_{ij,2} &= Z_{i-1,j} - 2Z_{i,j} + Z_{i+1,j} - f_{ij,2} = 0 \\ F_{ij,3} &= Z_{i-1,j+1} - 2Z_{i,j} - Z_{i+1,j-1} - f_{ij,3} = 0 \\ F_{ij,4} &= Z_{i,j+1} - 2Z_{i,j} - Z_{i,j-1} - f_{ij,4} = 0 \end{aligned} \quad (2)$$

where $F_{ij,1}, F_{ij,2}, F_{ij,3}, F_{ij,4}$ = pseudo observation equations,
 $Z_{i,j}, Z_{i+1,j+1}, Z_{i+1,j}, Z_{i+1,j-1}, Z_{i,j+1}, Z_{i,j-1}, Z_{i-1,j+1}, Z_{i-1,j}, Z_{i-1,j-1}$ = elevations of a center post and its eight neighboring posts,

$f_{ij,1}, f_{ij,2}, f_{ij,3}, f_{ij,4}$ are computed as follows:

$$\begin{aligned} f_{ij,1} &= l_{i-1,j-1} - 2l_{i,j} + l_{i+1,j+1} + v_{ij,1} \\ f_{ij,2} &= l_{i-1,j} - 2l_{i,j} + l_{i+1,j} + v_{ij,2} \\ f_{ij,3} &= l_{i-1,j+1} - 2l_{i,j} - l_{i+1,j-1} + v_{ij,3} \\ f_{ij,4} &= l_{i,j+1} - 2l_{i,j} - l_{i,j-1} + v_{ij,4} \end{aligned} \quad (1)$$

where $l_{i,j}, l_{i+1,j+1}, l_{i+1,j}, l_{i+1,j-1}, l_{i,j+1}, l_{i,j-1}, l_{i-1,j+1}, l_{i-1,j}, l_{i-1,j-1}$ = observed elevations for center post and its eight neighbouring posts.

2.2 Observation equations for the least squares matching model

Least squares matching models are used to represent the correspondence between the gray levels in two image fragments via a geometric model, (Helava 1988 and Gruen 1985). In pairwise least squares matching, pixel gray values in one image, i.e. template image, are arbitrarily chosen to be constants, while

pixel gray values in the other image, i.e. patch image, are chosen to be observations. In the multi-photo least squares matching, Figure 2, one observation equation is written between the intensities of two corresponding pixels in each image pair. Each observation equation states that the difference in the gray level between the two pixels is zero, Eq. (3).

$$\begin{aligned} G_{ij}^{12} &= g_{ij}^1 - g_{ij}^2 = 0 \\ G_{ij}^{23} &= g_{ij}^2 - g_{ij}^3 = 0 \\ G_{ij}^{34} &= g_{ij}^3 - g_{ij}^4 = 0 \\ G_{ij}^{45} &= g_{ij}^4 - g_{ij}^5 = 0 \end{aligned} \quad (3)$$

where G_{ij}^{12} , G_{ij}^{23} , G_{ij}^{34} , G_{ij}^{45} = least squares matching equations,
 g_{ij}^1 , g_{ij}^2 , g_{ij}^3 , g_{ij}^4 , g_{ij}^5 = gray values for one pixel representing post (i,j) in images 1,2,3,4 and 5 respectively.

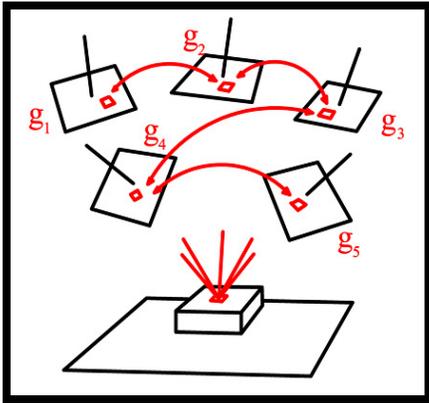


Figure 2. Multi-photo least squares matching for one DEM post

The gray level in each image is function of the position of the pixel. Hence, the adjusted pixel location could be determined. This is achieved by minimizing a goal function, which measures the differences between the gray levels in the template and the patch images. The goal function to be minimized is the L2-norm of the residuals of the least squares estimation. The location of the pixel is described by the elevation of the corresponding DEM post, Eq. 4.

$$\begin{aligned} G_{ij}^{12} &= G(g_{ij}^1, g_{ij}^2, Z_{ij}) \\ G_{ij}^{23} &= G(g_{ij}^2, g_{ij}^3, Z_{ij}) \\ G_{ij}^{34} &= G(g_{ij}^3, g_{ij}^4, Z_{ij}) \\ G_{ij}^{45} &= G(g_{ij}^4, g_{ij}^5, Z_{ij}) \end{aligned} \quad (4)$$

where G_{ij}^{12} , G_{ij}^{23} , G_{ij}^{34} , G_{ij}^{45} = least squares matching equations,
 g_{ij}^1 , g_{ij}^2 , g_{ij}^3 , g_{ij}^4 , g_{ij}^5 = gray values for one pixel representing post (i,j) in images 1,2,3,4 and 5 respectively,
 Z_{ij} = adjusted elevation for post (i,j).

2.3 Implementation

For a DEM of M rows and N columns, the number of unknowns is NxM. There exists NxM observation equations and (4xNxM-n) pseudo observation equations (where n = number of intersections between any linear feature and the line segment linking two posts). In addition, for each DEM post there are (m-1) intensity observation equations (where m = number of images used in the least squares matching process). However, intensity observation equations that belong to obscured pixels are removed.

For each DEM post, obscured pixels are found using the following procedure. The 3D ray between the post and the image perspective center is generated using 3D coordinates of the post and the image registration information. All neighboring posts are tested and if one neighboring post is above the ray, the intensity of this image is not included in the least squares matching model. The procedure is applied with all images for each DEM post.

The refinement process is implemented recursively. In the first iteration, the elevations of the original DEM are used as the initial DEM. In the following iterations, the refined DEM of the preceding iteration is used as the initial DEM. The iterations stop when the refinement is insignificant.

3. EXPERIMENTAL RESULTS AND ANALYSIS

To test and verify the proposed algorithm five DEMs are generated using a dataset of 1:4000 scale aerial photographs scanned at 30µm. The aerial photographs were taken with 80% overlap and 60% sidelap. The DEMs are generated with one meter post interval. The set of imposed breaklines are digitized from the same aerial photographs. A reference DEM is collected manually for each test site. The differences between the elevations of the reference DEMs and the ATE DEMs are computed. In addition, the differences between the elevations of the reference DEM and the refined DEMs are also computed. Table 1 shows the computed RMS for both differences. The mean value of the RMS for the original DEMs is about ten centimeters. The mean value of the RMS for the refined DEMs is five centimeters. Figures 3, 4, 5, 6, and 7 show a perspective view of the original DEMs and the refined DEMs for the five test site.

Test site	Number of posts	RMS (cm)	
		Original DEMs	Refined DEMs
1	21000	8.2	4.1
2	9600	7.7	4.0
3	6400	10.5	6.2
4	2100	9.1	5.3
5	19600	14.8	7.9

Table 1. RMS for original and refined DEMs

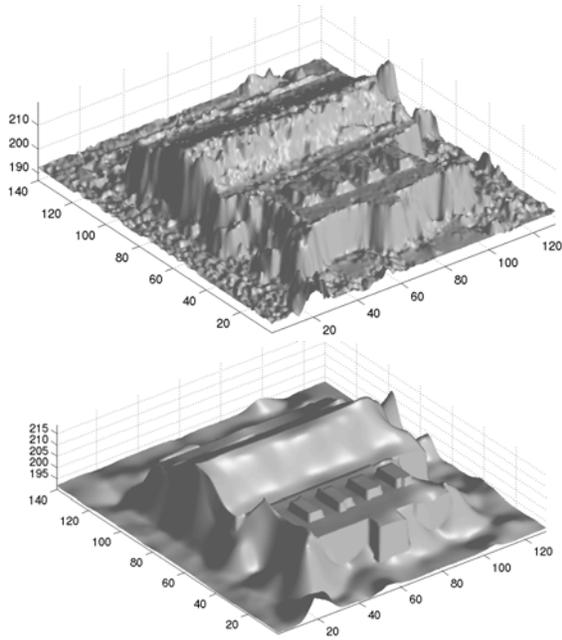


Figure 3. The ATE DEM (up) and the refined DEM (down), 1

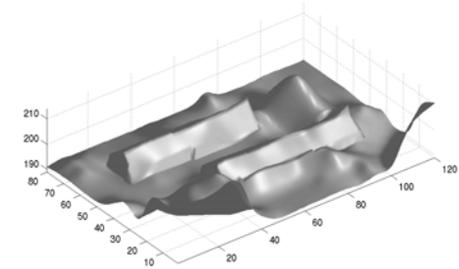
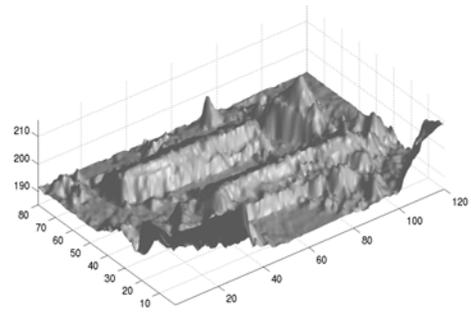


Figure 5. The ATE DEM (up) and the refined DEM (down), 3

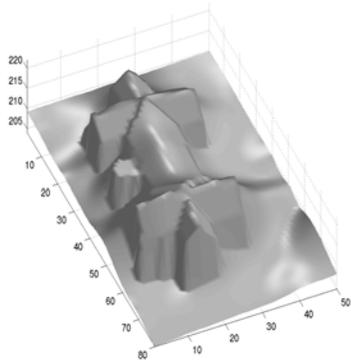
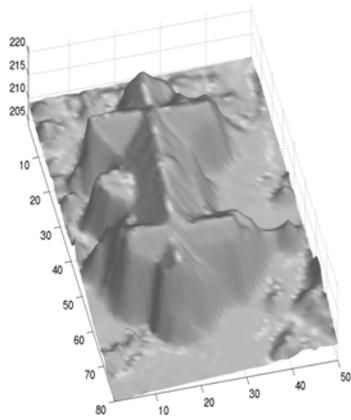


Figure 4. The ATE DEM (up) and the refined DEM (down), 2

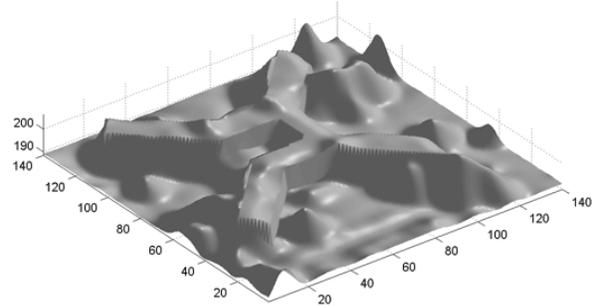
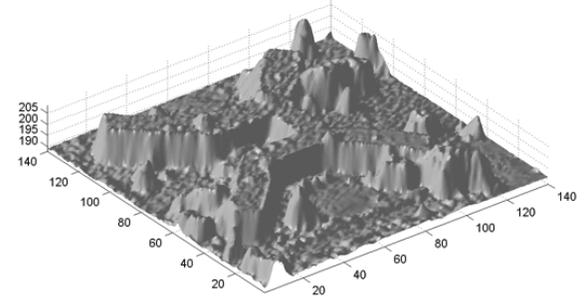


Figure 6. The ATE DEM (up) and the refined DEM (down), 4

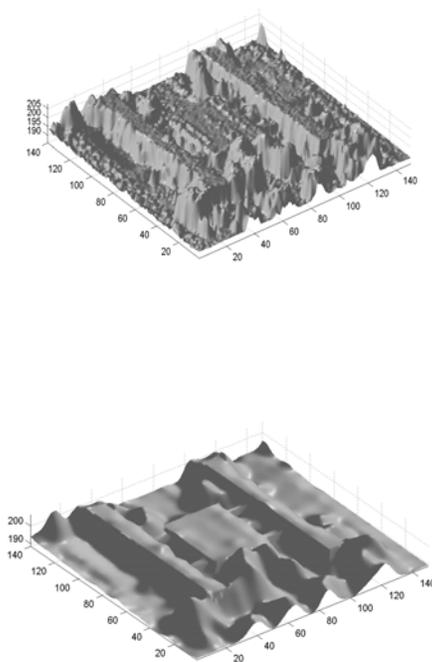


Figure 7. The ATE DEM (up) and the refined DEM (down), 5

4. CONCLUSIONS

Automatic terrain extraction techniques fail to provide accurate and reliable DEMs. However, high quality DEMs are essential for a variety of applications. In this paper, a new algorithm is developed to improve the validity and quality for DEMs in urban areas. Surface continuity is forced between each DEM post and its neighboring posts, except in the vicinity of breaklines. In addition, the elevation of each DEM post is employed in a multi-photo least squares adjustment model. Obscured pixels are eliminated from the adjustment. The model modifies the elevation of each DEM post in order to minimize the variations of the intensities of corresponding pixels in all employed aerial images. The RMS of one meter resolution DEMs in five sites are reduced from ten to five centimeters. Future research will focus on the use of automatically extracted breaklines in the refinement process.

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